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EFFECTS OF ROLLING SPEED ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF AL-1050-H4 DURING ACCUMULATIVE ROLL BONDING (ARB)

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ABSTRACT

The aim of the study was to investigate the effects of rolling speed on microstructure and mechanical properties of AL-1050-H4 alloy during deformation by accumulative roll bonding. Samples were rolled at three different rolling speeds (9, 18 and 36 rpm) for single pass. Samples were annealed at 550˚C for 30 mins and air cooled. Light Optical Microscope (LOM) was used to get micrographs. During sample characterization, linear intercept method ASTM E112 standard was adopting. micro-hardness test was performed on un-rolled and rolled sample using ASTM E384 test method. Significant grain refinement was noticed from microstructure of sample rolled at higher speed (36 rpm) and was reported to be 46.6 µm. Un-rolled sample was the softest with a hardness of 40.3 HV. Accumulative roll bonding enhanced AL-1050-H4 as maximum hardness (49 HV) was obtained on a sample rolled at 36 rpm. Material hardness was increased by 18% at single pass in this study.

KEYWORDS: Speed, ARB, Sample, Microstructure, Properties & Size

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Original Article

1. INTRODUCTION

Lightweight materials are in the focus of the development of novel structural materials, as they bear the potential to reduce the energy consumption in mobile applications while retaining the functionality[1]. Aluminium alloys have been commonly used in the automotive and aerospace industries in recent years. In particular, this is due to the real need to save weight to further minimize fuel consumption and exhaust emissions[2]. A new approach for processing ultrafine grain materials with improved mechanical properties is extreme plastic deformation[3].Reducing the grain size of polycrystalline metallic materials is an economic way to improve the mechanical properties such as strength, and toughness[4].Grain size refinement is most appropriate for enhancing strength without losing ductility. Other SPD processes have the following drawbacks, such as Equal Channel Angular Pressing, High Pressure Torsion, Cyclic Extrusion Compression, Continuous Confined Strip Shearing, and Mechanical Milling. First, the forming dies needed are very expensive; the forces necessary are also extremely strong. Secondly, it is found that the above methods are inadequate for the processing of bulk materials[5].Recent studies have shown that extreme plastic deformation (SPD) techniques are very successful in refining the microstructure and improving the mechanical properties of magnesium alloys, such as equal-channel angular pressing (ECAP), accumulative roll bonding (ARB), high pressure torsion (HPT), multidirectional forging (MDF) and cyclic closed-die forging (CCDF)[6].One of the most known processes for producing composite sheets from metallic sheets and for producing clad sheets is roll bonding[7]. Accumulative roll bonding (ARB) has the ability to become an industrial method for the processing of metal sheets of composite and ultrafine grain (UFG)[8].Roll bonding (RB) and ARB are the solid-state welding processes used by rolling to bond similar or different metals; these methods are simple and low-cost methods of producing sheet metal mass production[5].The material is cut into two during the ARB process, the pieces are

stacked on top of each other, and then rolled again to achieve a 50 percent thickness reduction[8].The rapid expansion of the railway network between 1830 and 1900 directed the early development of material testing[9].

Due to the random size and shape of the building blocks, whose mean values and dispersions may not be the same, the overall mechanical properties of nanomaterials have also been shown to be quite different[10].For the determination of hardness, static indentation hardness measures such as Brinell, Rockwell, Vickers, and Knoop are widely used methods. For cutting tolls, wear and abrasion-resistant materials, prosthetic hip joint balls and sockets, hardness is key[11]. Hardness is a property assessed by determining the resistance of an applied load to deformation[12]. A high velocity has a major impact on Mg alloy deformation, which is summarized in two ways. On the one side, it easily results in a high deformation rate that gives rise to shear bands. On the other hand, the heat of deformation is increased and the conduction heat is confined to cold rolls, resulting in higher temperatures to facilitate recrystallization[13].The hardness test method of Vickers consists of indenting the test material with a diamond indenter in the shape of a pyramid with a square base and a 136 degree angle between opposite faces subjected to a test force of between 1gf and 100kgf[14].Indentation hardness evaluation is a convenient way of studying a specific amount of materials' mechanical properties. The Vickers micro-hardness process theory is similar to the (macro) hardness measure, with the exception of slightly smaller loads[15].The effect of rolling velocity on Al strip intensity at elevated temperatures has been investigated byQuadir et al. in 2007 and 2008. While scattered knowledge was produced at elevated rolling temperatures[16]. Rolling speed by accumulative roll bonding has a major effect on nanomaterial development time. In order to determine the required rolling speed, the effect of rolling speed on material macrostructure and mechanical properties must be studied, resulting in more enhanced mechanical properties (hardness) of Aluminium 1050-H4.

In this paper, different speed rolling processing was adopted to investigate the effect of rolling speed on grain size and mechanical properties (hardness). Mechanical properties and microstructure of the differential-speed-rolled commercial AL- 1050-H4 samples were compared with un- rolled ones. The study shows the relationship between rolling speed, grain size and mechanical properties.

2. MATERIAL

Aluminium alloy 1050-H4 samples whose chemical composition is listed in table 1 were rolled at room temperature of 22^{0}C at the speed of 9, 18 and 36 rpm for single ARB cycles.

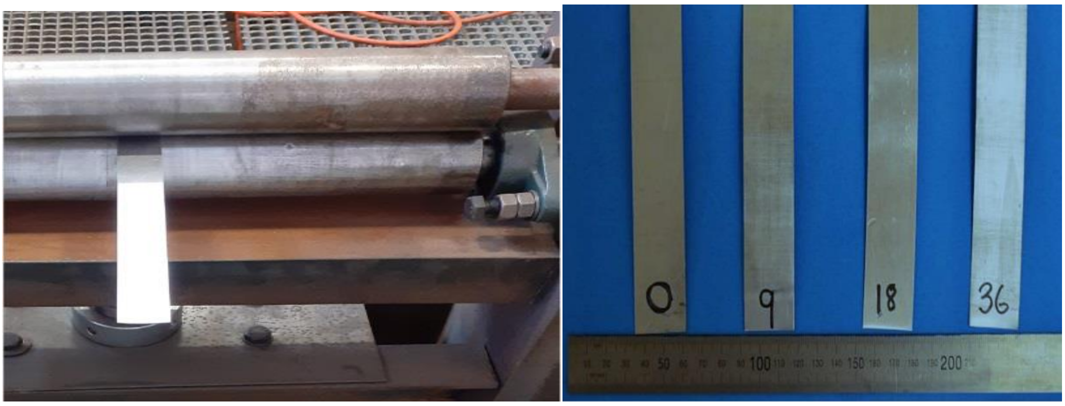
Table 1: Chemical Composition of Aluminium Alloy 1050-H4

Cast No.	Alloy	O (%)	Fe (%)	Si (%)	Ag L	Al (%)
18122A44	1050	2.66	0.47	10.27	1.06	85.54

3. ARB EXPERIMENT

This study used traditional rolling equipment with two horizontal shafts that are free to rotate by means of automated mechanical action. The material used was Aluminium (Al 1050-H4) of 220mm x 25mm x 0.9mm. The rollers were aligned by using a filler gauge across to make sure that the gap is the same across the rollers. At different speeds of 9, 18 and 36 rpm, three ARB experiments were performed. For all rolling speeds, the force applied between the rollers was 3 tons. During the deformation phase, the samples for the first pass were pushed through the rollers. The specimen was grasped by two horizontal shafts and pulled through the rollers. Figure 1(a-b) shows two roller rolling machines and rolling samples. The thickness before and after the pass was measured using the Venier calliper. The collected ARB data is presented in

table 2. Samples were cut in the rolling direction for microscopy observation and micro-hardness examination, before and after ARB pass.



(a) (b)

Figure 1: (a) Rolling Process and (b) Rolled Samples.

Table 2: Thickness Reduction and Rolling Speed.

Thickness Reduction (mm)	Rolling Speed (rpm)
0.9	0
0.639	9
0.635	18
0.634	36

3.1 Sample Preparation and Characterization

Strip samples of 4 cm length were cut from supplied long strips on rolling direction. Then each sample was bent at 90 degree at a length of 1 cm, to strength its settlement on hot mount resin. The bent samples were mounted in transparent resin using hot mount press. The mounts were plane ground using SiC paper of size 120 and 320. Thereafter were fine ground using SiC paper of size 800 and 1200. The grinding speed was 300 rpm of base disc and 150 rpm of sample holder disc, rotating in similar direction. Thereafter were given surface polish in sequence of 9 um. 6 um, 3 um and 1 um diamond polishing lubricant. The polishing cloths used were MD Mol, MD Mol, MD Nap and MD Largo respectively. Anodising was done using Barker reagent solution, and samples were electro polished for 10mins, at DC Voltage of 24 V with current density of 0.2 A/cm^2.Thereafter were rinsed with ethanol, dried and examined under light optical microscope. Samples were annealed at 550°C for 30 mins and air cooled. During sample characterization, linear intercept method ASTM E112 standard on image-J application platform was adopting.

3.2 Micro- Hardness

Samples were cut on rolling direction (RD) and mounted before hardness test was performed. The test was performed on parent sample (sample before rolling) as well as rolled samples using EMCO Test Dura Vision instrument. ASTM E384 test method was adopted. For statistical consideration five indentations were made at different positions per sample. Force of 1000g was applied in all the samples and the load holding time was 10 seconds.

4. RESULTS AND DISCUSSIONS

From table 2, it was observed that thickness reduction was the same for three different rolling speed at applied constant load of 3 ton. Microstructure of sample before and after rolling at different speeds are shown in figure 2 (a-d) average grain size measured by linear intercept are presented in Table 3. Grains are more homogeneous on parent sample which is shown on figure 2a. It is the indication that the material was not subject to any stress. From the same figure it was noticed that grains are bigger (57.5 µm) as to compared to rolled samples. It was noticed from Figure 2b that grain elongated along rolling direction due to applied force and shearing during material rolling where the rolling speed was reported to be 9 rpm. There is a small decrease (2.2 µm) in grain size at this rolling speed. Significant decrease in grain size was notice in Figure 2d, where the rolling speed was 36 rpm and average grain size was reported to be 46.6 µm. Smaller equiaxed grains are noticed in microstructure of sample rolled at 36 rpm, which indicate early recrystallisation during ARB. Figure 2d shows high curvature as compared to other microstructures. This implies that material mechanical properties are more enhanced at this sample.

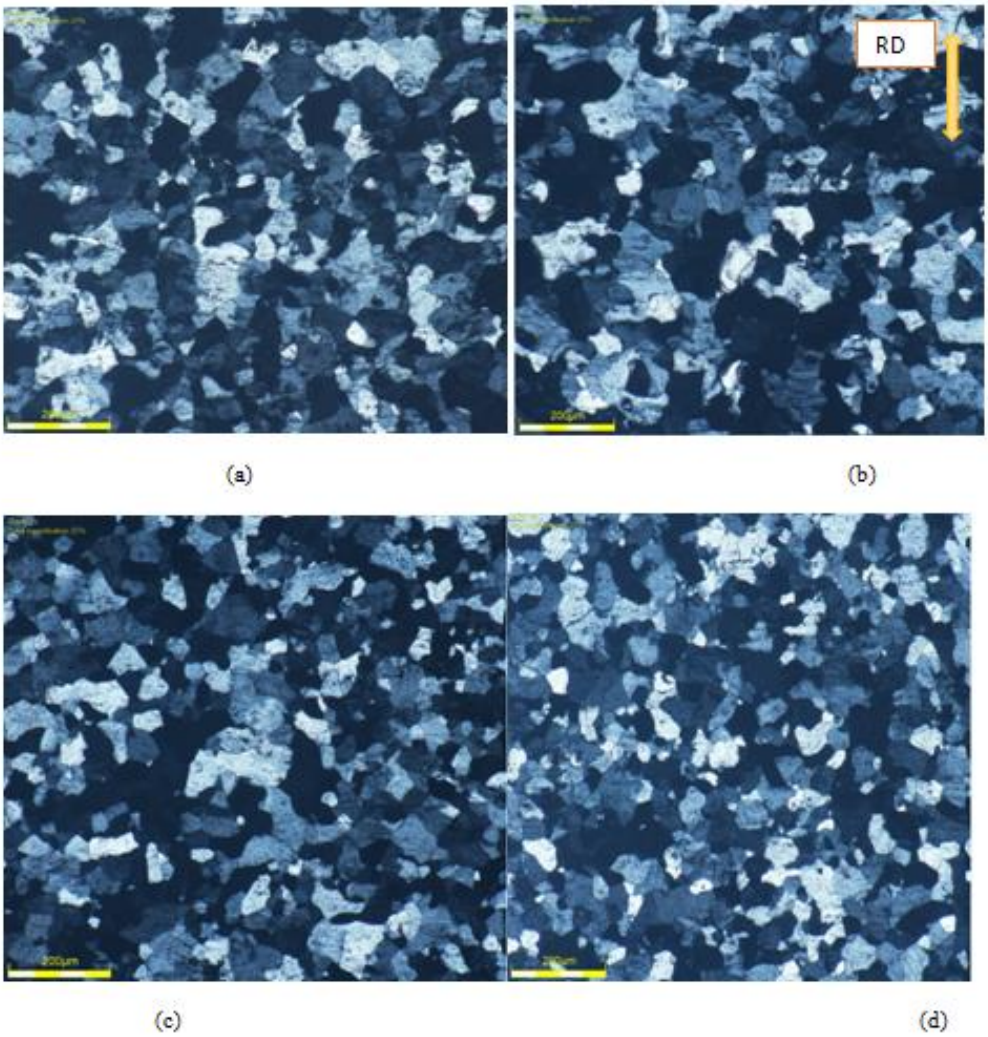


Figure 2: (a) Microstructure of Parent Sample, (b) Microstructure of Sample Rolled at 9 rpm, (c) Microstructure of Sample Rolled at 18 rpm and (d) Microstructure of Sample Rolled at 36 rpm.

Table 3: Grain Size Measurements using Linear Intercept (ASTM E112)

Rolling Speed (rpm)	Average Grain Size (µm)
0	57.5 ± 2.4
9	55.3 ± 2.5
18	50.4 ± 2.6
36	46.6 ± 2.4

The results obtained from micro-hardness test and table 3 are graphically presented in figure 3 and 4.It was noticed from figure 3 that sample of material before rolling was the softest when compared to rolled samples and the hardness was reported to be 40.3 HV. The sample rolled at 36 rpm was noticed to be the hardest as it was 49 HV. Accumulative roll bonding enhanced Al- 1050-H4 mechanical properties [5][2]. At higher rolling speed material hardness was increased by 18% at single pass. Figure 4 revealed that ARB reduces grain size and it was notice that significant grain size reduction was on the sample rolled at high speed. From the same Figure, it was seen that reduction in grain size increase material hardness[17][18][19]. It was as well reported on the study of effect of surface temperature and particle size on mechanical properties during ARB that decrease in grain size increase mechanical properties by[20]. In determining the mechanical properties of almost all crystalline materials and thus ultra-fine grained materials, average grain size plays an important role[16].Due to their superior mechanical properties, materials with sub-micron mean grain size are commonly used[16]. From the study of Accumulative Roll Bonding of Pure Copper and IF Steel, it was reported that IF samples hardness increased rapidly at initial stage[21].

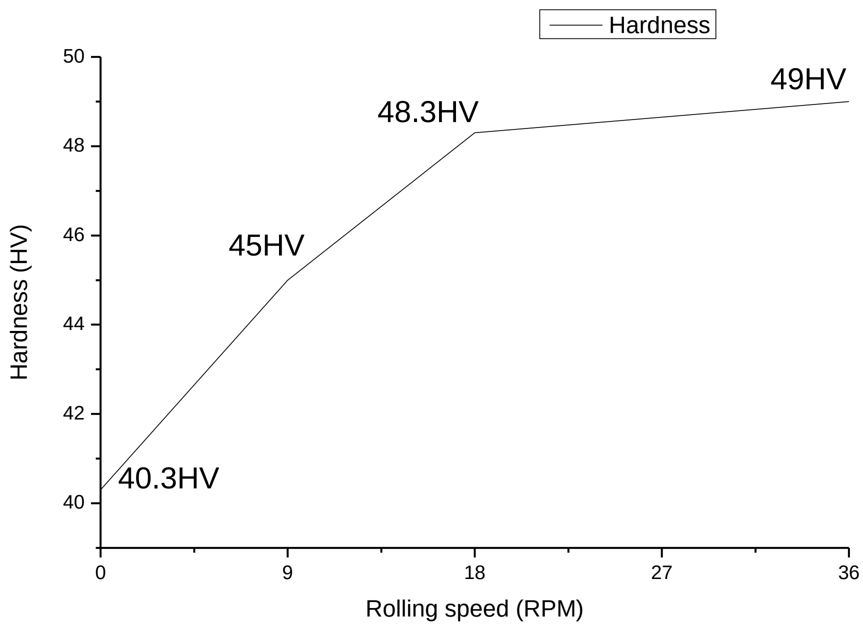


Figure 3: Average Hardness (HV 0.1) at Different Rolling Speed.

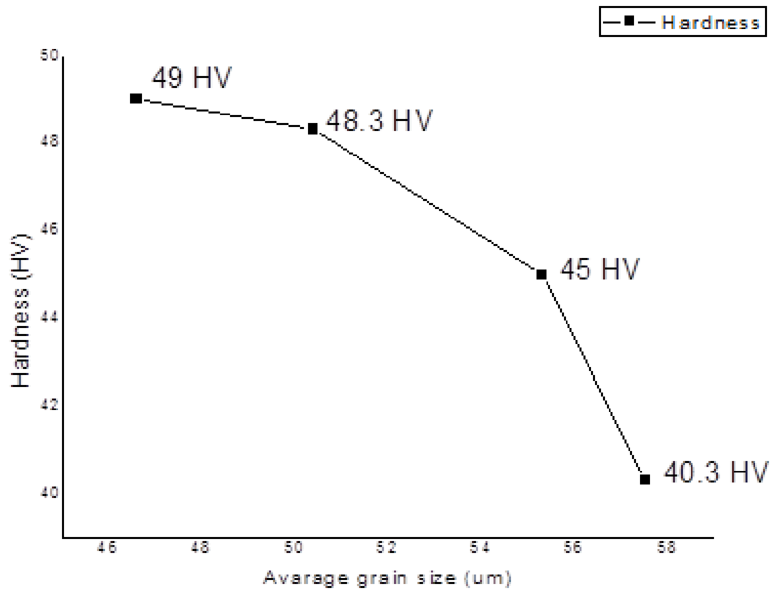


Figure 4: Average Grain Size at Different Rolling Speed.

5. CONCLUSIONS

In this present study it has been seen that better grain refinement obtained at higher rolling speed which, was reported to be 36 rpm. At this speed, average grain size was reduced from 57.5 µm to 46.6 µm. The grain size reduction was noticed to be 18%.Smaller equiaxed grains were noticed in microstructure of sample rolled at 36 rpm, which indicate early recrystallisation during ARB process. There was not much grain size reduction at a slower rolling speed (9 rpm) which was reported to be 2.2 µm. un-rolled sample was noticed to be the softest as it was reported to be 40.3 HV. Material mechanical property (hardness) is more enhanced at higher rolling speed and was reported to be 49 HV. This shows that accumulative roll bonding enhances material mechanical properties. High material hardness was noticed on the sample which have smaller average grain size which, is the indication that the decrease in grain size increases material properties. It can be concluded based on this study that high rolling speed result in more refined grains and enhanced mechanical properties.

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